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GEOLOGY RELATED TO ACOUSTIC TRANSMISSION: EASTERN CARIBBEAN.(U)
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NORDA Report 28

Geology Related to Acoustic Transmission: Eastern Caribbean

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Sea Floor Division
Ocean Science and Technology Laboratory

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Foreword

Sound transmission can be greatly affected by variations in the geologic properties of the sea floor. Sound velocities may vary both horizontally and vertically as geology varies from basin to basin. This report presents the geologic characteristics of the eastern Caribbean which are of significance in the use and understanding of typical velocity patterns found in the region. Compiled from all available sources, the report brings together the most important of these geologic factors.

G. T. Phelps

G. T. Phelps, Captain, USN
Commanding Officer
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Executive Summary

Geologic characteristics of the ocean floor can produce measurable effects on sound speed. Of significance are the intrinsic properties of sediments, their depth of burial, degree of consolidation, and temperature. Roughness of the sea floor can also affect sound transmission.

The series of maps in this report depict sound velocities beneath the eastern Caribbean as they vary both horizontally and vertically with geologic variations in the sea floor, together with the areal distribution of other important geologic factors which affect sound speed. A brief discussion of each map is included in the text.

The sound speed map (Fig. 1) was compiled from all available seismic refraction data. Presented in columnar form, the map displays the variations in sound speeds which take place with depth beneath the sea floor; corresponding geologic variations are given. Also appearing on the map are contours of bottom water sound speeds.

North-south and east-west cross sections (Fig. 2) were constructed from the same data. These show the patterns of geologic and acoustic stratification in the region and the underlying basin structure.

Other important geologic factors which affect sound speed can be encountered at or near the surface of the sea floor; their distribution is shown on the remaining maps.

For the map of surficial sediments and their velocities (Fig. 3), sediment types were obtained from core descriptions. Grain size, a most significant factor that affects sound speeds in sediments, can be inferred from sediment types, and sound velocities are listed for each equivalent grain size category. On the heat flow map, (Fig. 4) the values depicted were obtained from several sources. The degree of reliability of older data is noted at each station location.

The map of bottom roughness (Fig. 5) was constructed from seismic reflection records. Shown are areas of microtopography whose dimensions are too small to appear on most topographic maps, together with the topographic provinces.

The data were compiled from a variety of sources and aspects. More detailed information may be obtained from the references listed.

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Contents

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Geology Related to Acoustic Transmission: Eastern Caribbean

I. Introduction

Acoustic transmission can be greatly affected by variations in the geologic properties of the sea floor. Sound velocities may vary both horizontally and vertically as the geology varies from basin to basin. Knowledge of characteristic geologic differences as they exist in the eastern Caribbean is advantageous in the use and understanding of typical velocity patterns found in the region.

The eastern Caribbean, as defined here, consists of the Venezuela and Grenada Basins, which are separated by the submerged north-south Aves Ridge. The generally smooth floor and slopes of the Venezuela Basin differ greatly from those in the Grenada Basin, where a highly complex and irregular sea floor exists in the northern sector in contrast with a smooth and flat-lying abyssal plain in its southern portion. Each of these topographic provinces has further individual geologic distinctions which can cause variations in sound transmission.

Significant geologic characteristics which can affect sound speed are: the intrinsic properties of sediments, their depth of burial, their degree of consolidation, and bottom temperature. Bottom roughness can also affect sound transmission.

The maps included here depict sound speeds in the eastern Caribbean as they vary both horizontally and with depth, and show the areal distribution of some of the geologic factors which affect sound speed. Sources and more detailed information about the data that were used may be found in the list of references.

II. Sound Speed Map (Fig. 1)

This map, a compilation of all available sound speed data, depicts, in column form, the sound speeds which are found in the sediments and crust of the eastern Caribbean. Also included on the map are estimates of bottom water sound speeds. The columns were constructed from seismic refraction and reflection data obtained by two field techniques. The earlier seismic refraction profiles are from two-ship surveys (Edgar et al., 1971; Ewing et al., 1960; and Officer et al., 1959) and the more recent seismic reflection profiles are from a single ship using a sonobuoy (Ludwig et al., 1975). Velocities determined by both methods are usually compatible with each other and with those from JOIDES boreholes (Saunders et al., 1973). However, in the two-ship method, detailed information just beneath the sea floor is sometimes obscured; the second method usually affords greater resolution, but is limited in depth.

There is no unique correspondence of sound speed with lithology; a compact limestone, basalt, or granite may all display the same velocity. However, some of the individual properties of the sediments and rocks themselves show correlation with velocities, particularly those related to porosity and density (Horn et al., 1968). Sound speed beneath the sea floor usually increases with depth, as lithostatic or hydrostatic pressures squeeze out porewater from within the sediments and compaction takes place. Consolidation of sediments, accomplished either chemically or through compaction, increases sound speed. Rocks of greater density, such as igneous or volcanic rocks, and those found deep within the crust of the earth under great pressures, also display greater velocities. The

progression of sound speed with depth is demonstrated in the columnar velocity structures on the map.

Throughout most of the Venezuela Basin, there is a characteristic subsurface geologic sequence which was earlier referred to as the "Carib Beds" (J. Ewing et al., 1967). These can be identified by the presence of two prominent and widespread reflectors. Horizon A", the uppermost reflector, usually denotes the separation of unconsolidated and consolidated sediments and their distinctive velocities. Horizon B", the lowermost of the two strong reflectors, is usually the deepest observed in the basin on single-channel, unprocessed seismic reflection records. Beneath Horizon B", still higher velocities are occasionally found and are believed to indicate a mixture of rock types (Ludwig et al., 1975). The infrequent sub-B" reflectors could also represent lateral changes in lithology as well as velocity changes with depth.

The sequence is remarkable for its uniformity of thickness and sound speeds. While it is most widespread in the Venezuela Basin, it has not been identified in the Grenada Basin. In contrast, in the Colombia Basin to the west, these beds are less easily recognized; there they are generally thicker and have higher velocities, and Horizon B" appears with a much rougher surface.

Beneath these upper stratified intervals, velocities continue to increase with depth, denoting in turn a low velocity crust, a high velocity crust and, finally, the mantle, which is the deepest observed. The velocity ranges for each of the layers depicted, together with the geologic materials they probably represent, are listed on the sound speed map (Fig. 1).

Bottom water sound velocity is approximately proportional to depth. The contours of in situ bottom water velocities which appear on the map were based on bathymetric contours for depths greater than 2000 m. Sound speed has been empirically determined to increase at a rate of 1.7 m per second for every 100 m increase in depth (Matthews, 1978).

III. Geologic and Acoustic Cross Sections (Fig. 2)

The cross sections further illustrate geologic structures and sound velocity structure in the eastern Caribbean. They are based primarily on data from Officer et al., 1959; Ewing et al., 1970; Edgar et al., 1975; and Ludwig et al., 1975. The velocities noted and the materials they probably represent correspond with those on the map of columnar velocities.

The data show that the central region of the Venezuela Basin is warped upward relative to its northern and southern margins. Great thicknesses of high and low velocity materials have accumulated near these margins in depressions or trenches formed by the descending mantle and the overlying high velocity layer which generally follows its configuration. On the east side of the basin, the mantle is also seen to descend west of Aves swell, where volcanic elements rise to form the ridge which separates the Venezuela and Grenada Basins. In this area mantle velocities, usually around 8 km per second, are lost as the mantle descends eastward to a depth below 50 km as Aves ridge is approached. Here, west of the ridge, the sediments again thicken over a mantle depression. To the east, mantle velocities have not been detected beneath the considerable masses of sediment in the Grenada Basin or under the volcanic Lesser Antilles arc.

For the most part, the uppermost sediments in the Venezuela Basin possess low velocities of 1.5 to 3.0 km per second and are generally remarkably uniform in thickness, thinning only on ridge crests, they do not follow the configuration of the mantle. Beneath these, materials of intermediate velocities from 3.5 to 7.5 km per second can be seen to have gradually filled in the

irregularities of the mantle surface, and except for a few places where volcanic materials have risen, these layers presented a fairly level surface for the later deposition.

In the southern part of the Grenada Basin, the uppermost portion of a deep north-south linear trough is filled with flat-lying low velocity sediments, most of which abut the ridge abruptly on the west and lap up onto the Antilles platform to the east. Beneath these, higher velocity materials are depressed near the center of the trough. In the northern part of the basin, while the uppermost sediments have been deformed and present a more uneven surface, they are generally of uniform thickness and continue onto the ridge.

IV. Map of Grain Size Ranges (Fig. 3)

Among the intrinsic properties of sediments which affect sound transmission, one of the most important is grain size. Studies have shown an increase in sound speed as grain size increases (Horn et al., 1968). Few quantitative analyses of grain size have been made on cores from the eastern Caribbean, but size may be inferred from sediment types in core descriptions. Designations of sand, silt and clay are frequently employed to denote size ranges, which are noted on the map, together with their corresponding velocities.

With the exception of calcareous sediments, where sizes may vary widely, it is not necessary to indicate actual mineralogical composition. In various ocean basins, deep sea sediments of the same mean or median grain size are apt to have the same velocities or to vary only about 1% (Hamilton, 1974).

Grain size in calcareous sediments varies widely according to the type of organisms or the degree of breakdown before or during deposition. In general, calcareous oozes often have a higher velocity than less calcareous sediments. The use of carbonate content alone in unconsolidated sediments is not a reliable index of sound velocity (Horn et al., 1968).

Much of the surficial cover in the eastern Caribbean is found to be calcareous (F.A. Bowles, unpublished data). Coarse sediments are usually found near source areas such as rivers and the submarine Aves Ridge, and where stronger currents have carried them to lower levels such as abyssal plains and the submarine channels which feed them. Clay interbedded with calcareous materials is found on the western slopes of Aves Ridge, with coarser deposits in the abyssal plains and in the deeper parts of channels.

V. Heat Flow (Fig. 4)

High heat flow results in a slight increase in acoustic velocities due to the increased geothermal gradient in soft sediments.

Prior to 1972, only 14 heat flow measurements had been made in the Caribbean (Epp, 1970). As their reliability is somewhat open to question, these values are shown on the chart with a number indicating their degree of reliability on a scale of 0 to 10. Measurements which are shown for the remaining 24 stations, labelled "W-72", may be considered more dependable (Clark, 1974).

Regional variations in heat flow may be caused by one or more factors, but most heat production is due to the energy released by decay of radioactive elements (Bullard, 1963). High heat flow values are usually associated with igneous intrusions or with frictional heating due to the earth's crustal movements, such as the subduction zones or where the rigid blocks or plates which comprise the earth's crust slide past each other. Tensional and compressional boundaries associated with island arcs, trenches and mid-ocean ridges generally show higher heat flow values than do shear zones, possibly because the latter have less vertical transport of material (Clark, 1974).

Large heat flow values in the vicinity of the Aves Ridge and in the Lesser Antilles and Tobago Trough regions provide support for the probable existence of subduction zones in those areas, although that beneath the Aves Ridge is believed to be no longer active. The smaller rises in values to the north and south in the Venezuela Basin suggest the possible presence of shear zones bounding the Caribbean in those areas, and contrast with the mid-level heat values in the east which may be more characteristic of compression.

VI. Bottom Roughness (Fig. 5)

This map outlines areas of bottom roughness whose dimensions are too small to be shown on the usual bathymetric charts.

Charts which employ contour intervals that are in general use show four overall types of topographic provinces in the eastern Caribbean: the usually smooth floor and slopes of the Venezuela Basin (IV); the prominences of Aves Ridge (III); the highly dissected and irregular bottom of the northern sector of the Grenada Basin (I); and the smooth, flat-lying abyssal plain in the southern part of that basin (II). Detailed study of seismic reflection records in the eastern Caribbean reveals a fifth type of topographic province (V) and, further, that a peculiar characteristic roughness is superimposed on the larger topographic features of more than half of the eastern Caribbean.

This type of roughness is most pronounced and has the greatest variation in both amplitude and wavelength in the northern part of the Grenada Basin (I). Most of these irregularities are less than 50 m in height and have wavelengths of 1 to 5 km. The few areas where their height ranges from 50 to just under 200 m are noted on the map. Smooth surfaces are found mainly in channel floors and where sediment drifts have piled up west of some of the passages between the Lesser Antilles islands in this area.

The small scale roughness continues to be visible on the western slopes of Aves Ridge (IV) and in the northern and central parts of the Venezuela Basin, although with a much more regular character and with smaller dimensions of 25 m or less in height. The irregularities become more subdued and die out to the west as the Venezuelan abyssal plain is approached; however, they reappear on the opposite slopes of the plain.

The southern part of the Grenada Basin is a smooth, flat-lying abyssal plain (II) where the only topographic irregularities are rounded hills to the east, near the bottom of the slopes of the island chain; these probably owe their origin to the gravity sliding of sediments which had accrued on the steep flanks of the islands.

In the southern part of the Venezuela Basin, on the western slopes of Aves Ridge, the fifth type of topographic province is found (V). Here the sea floor presents large, smooth undulations which increase in height and wavelength to the south. These are the surface expressions of great thicknesses of sediment that possess parallel reflectors near the top and are acoustically transparent beneath.

Examples of each type of topographic province were constructed from seismic reflection records (USNS WILKES, 1972).

VII. Summary

Each ocean basin has distinctive geologic characteristics which can affect sound speed. Knowledge of these characteristics will lead to a better understanding of acoustic behavior in a region. The series of maps and brief discussions in this report deals with these geologic factors and some of their effects on sound speeds in the eastern Caribbean; they comprise all pertinent material available at this writing.

The sound speed map (Fig. 1) demonstrates the increases in sound

velocities with depth beneath the sea floor, together with the types of geologic strata in which they occur. The map also shows that bottom water sound speeds increase as water depth increases.

The cross sections (Fig. 2) depict the patterns of geologic and acoustic stratification and the underlying structural features in the area.

Temperatures in the sediment beneath the sea floor vary with the amount of heat being supplied from below and with thermal conductivity. Possible sources of heat are discussed in the text, and heat flow values and their locations appear on the heat flow map (Fig. 3).

Grain size is one of the important factors which affect sound speeds in sediments. In Figure 4, sediment type, grain size, and their corresponding velocities demonstrate that sound speeds increase with increasing grain size. Positions of the cores from which information was obtained are indicated.

The final map in the series (Fig. 5) outlines areas of bottom roughness and designates the distribution of other characteristic forms of bottom relief. These also appear in cross section. Most of the irregularities are too small to appear on an ordinary topographic map, but they are capable of affecting the transmission of sound. More than half of the eastern Caribbean displays a rough microtopography.

The report calls attention to the geologic diversities in the eastern Caribbean which can affect sound speed, and brings together a variety of these factors. More detailed discussions may be found in the listed references.

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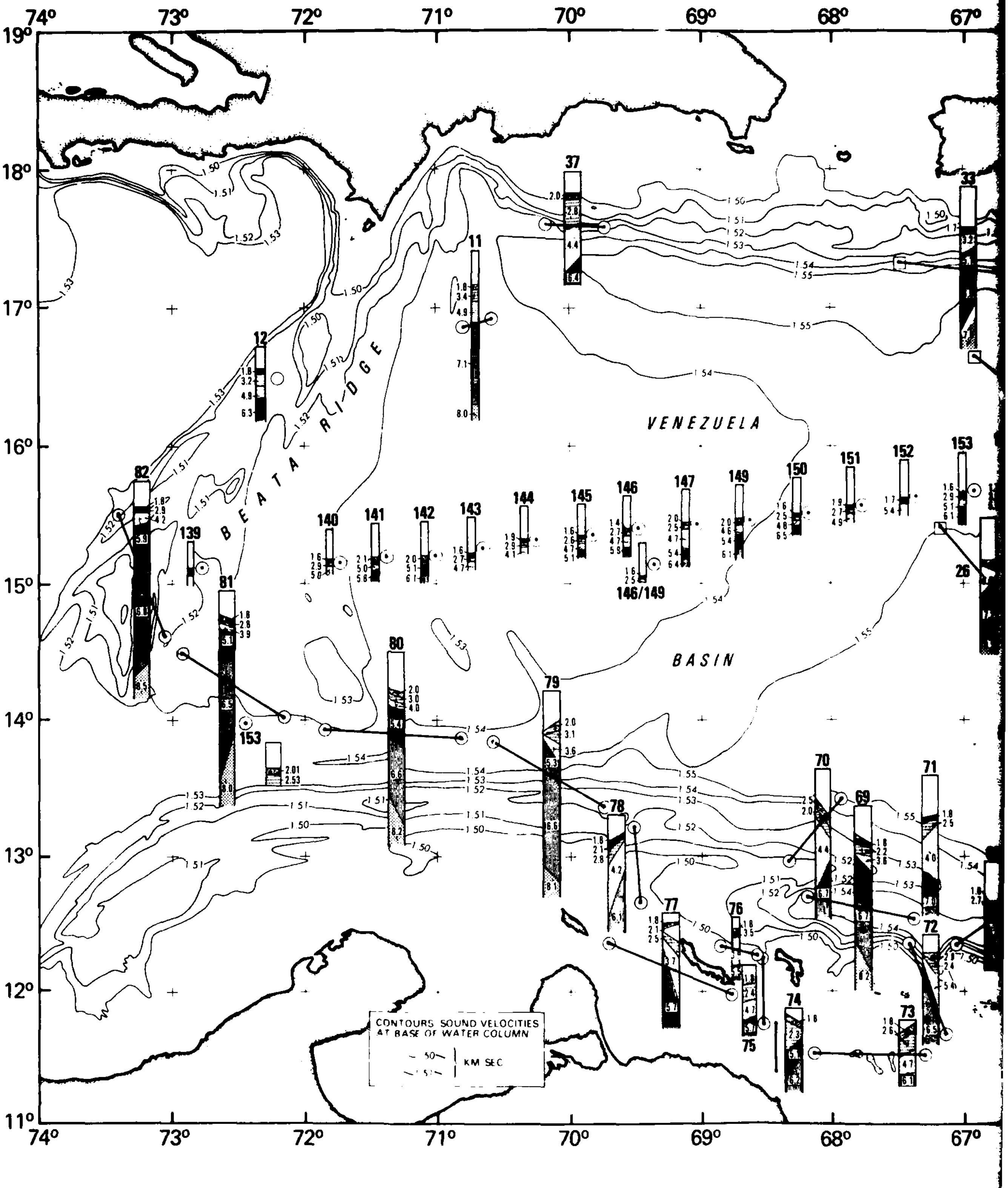
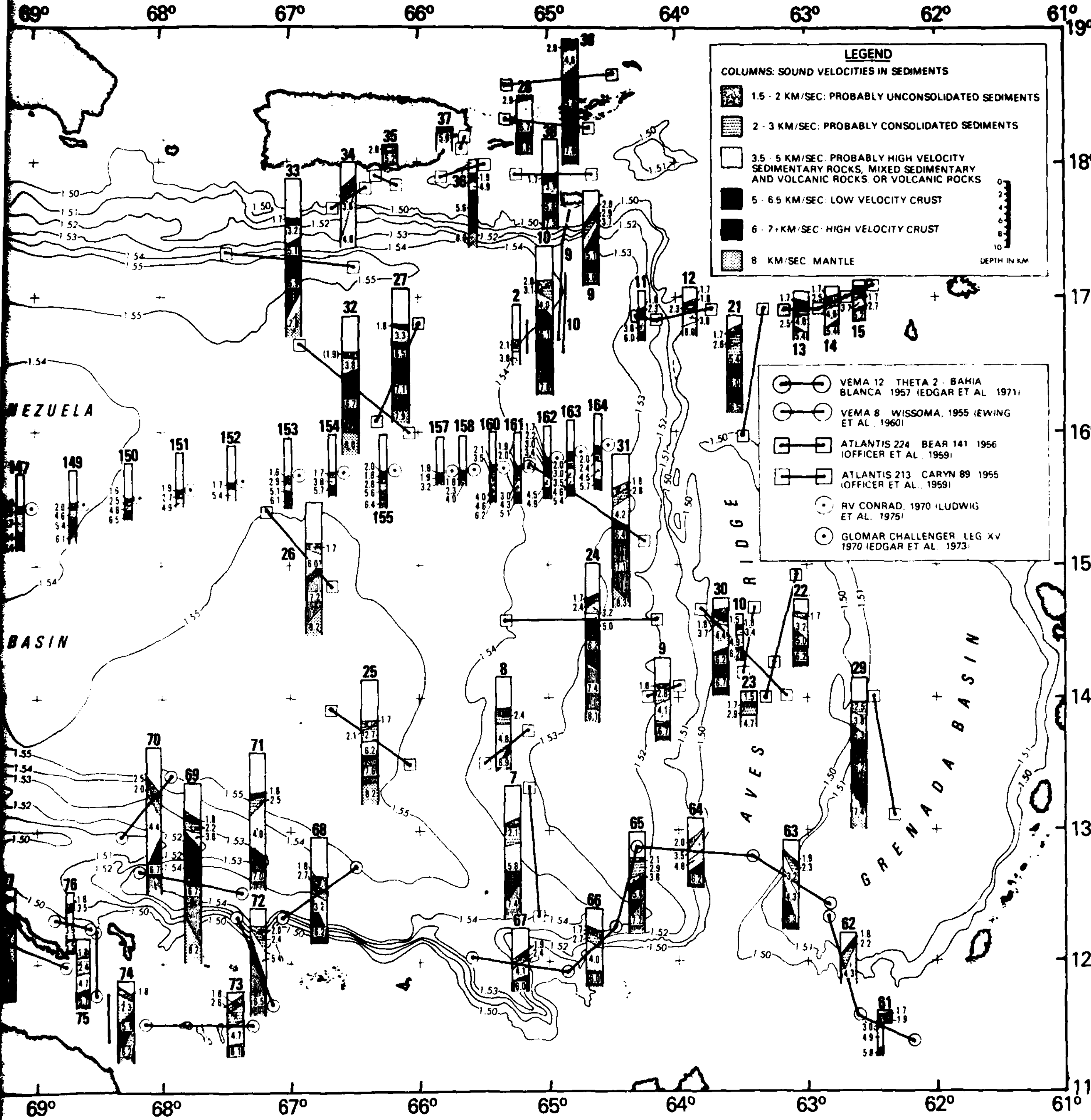


Figure 1. Sound speed map, constructed from seismic refraction data, shows increasing sound velocities beneath the sea floor and their probable geologic equivalents. Contours represent bottom water velocities as they increase with depth.



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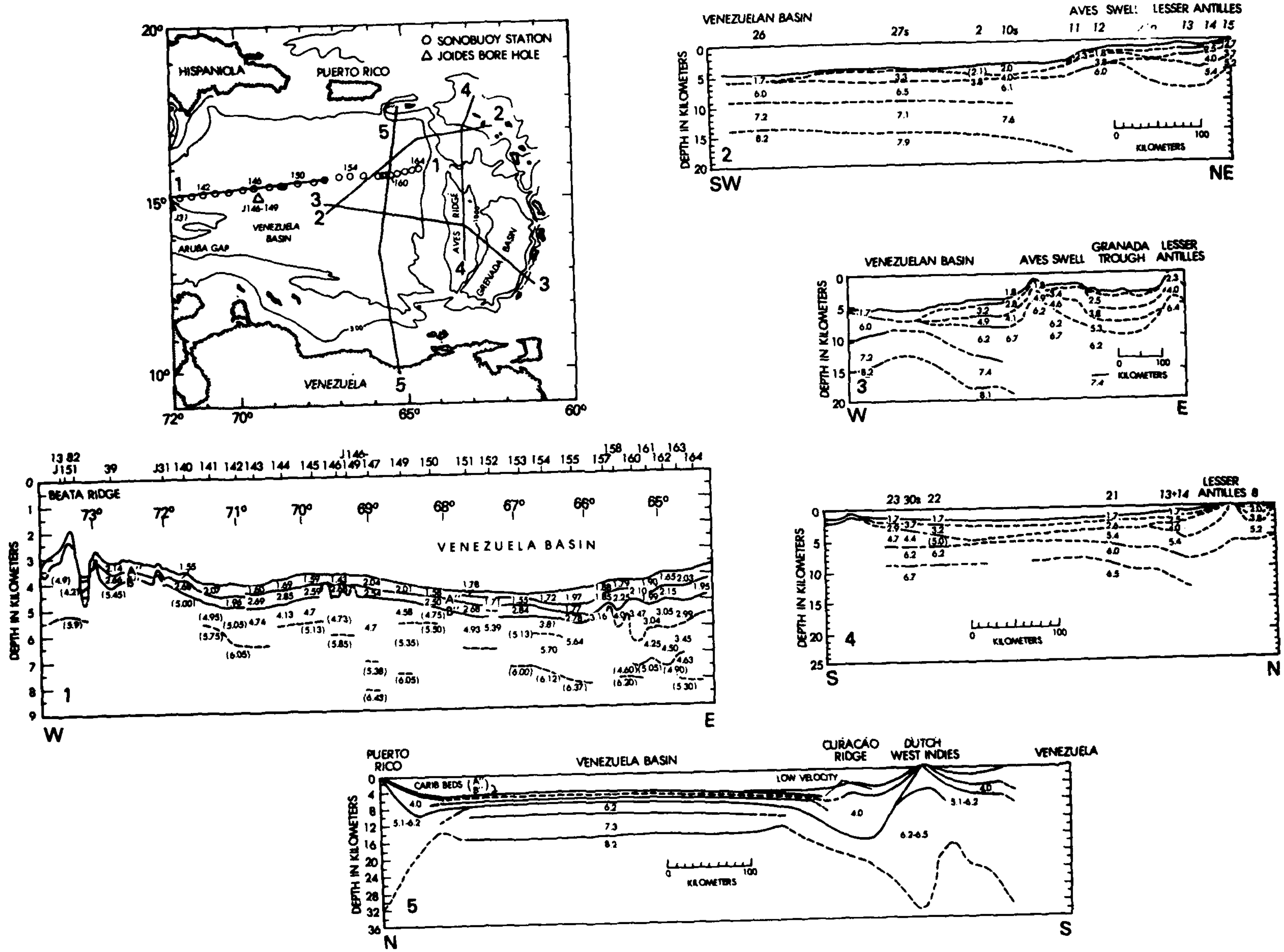

Figure 2. locations of geologic and velocity cross sections.

Profile 1: Seismic structure of Venezuela Basin west to east. Velocities in parentheses are from refracted waves, all others are interval velocities from wide angle reflections. "J" represents JOIDES drilling sites, asterisks denote assumed velocities of masked layers. (From Ludwig et al., 1975).

Profile 2: SW to NE. This profile begins near the middle of the Venezuela Basin, crosses the northern end of Aves swell and ends at the inner volcanic arc of the Lesser Antilles near Nevis. (From Officer et al., 1959).

Profile 3: South to north, from Aves swell to the inner volcanic arc of the Lesser Antilles at St. Eustatius. (From Officer et al., 1959).

Profile 4: West to east; starts in the Venezuela Basin, crosses Aves swell and the Grenada Basin, and ends at the Grenadines. (From Tomblin, 1975, based on Officer et al., 1959).

Profile 5: Spans the entire Venezuela Basin from north to south, from Puerto Rico to Venezuela. (From Ewing et al., 1970, and Edgar et al., 1971).

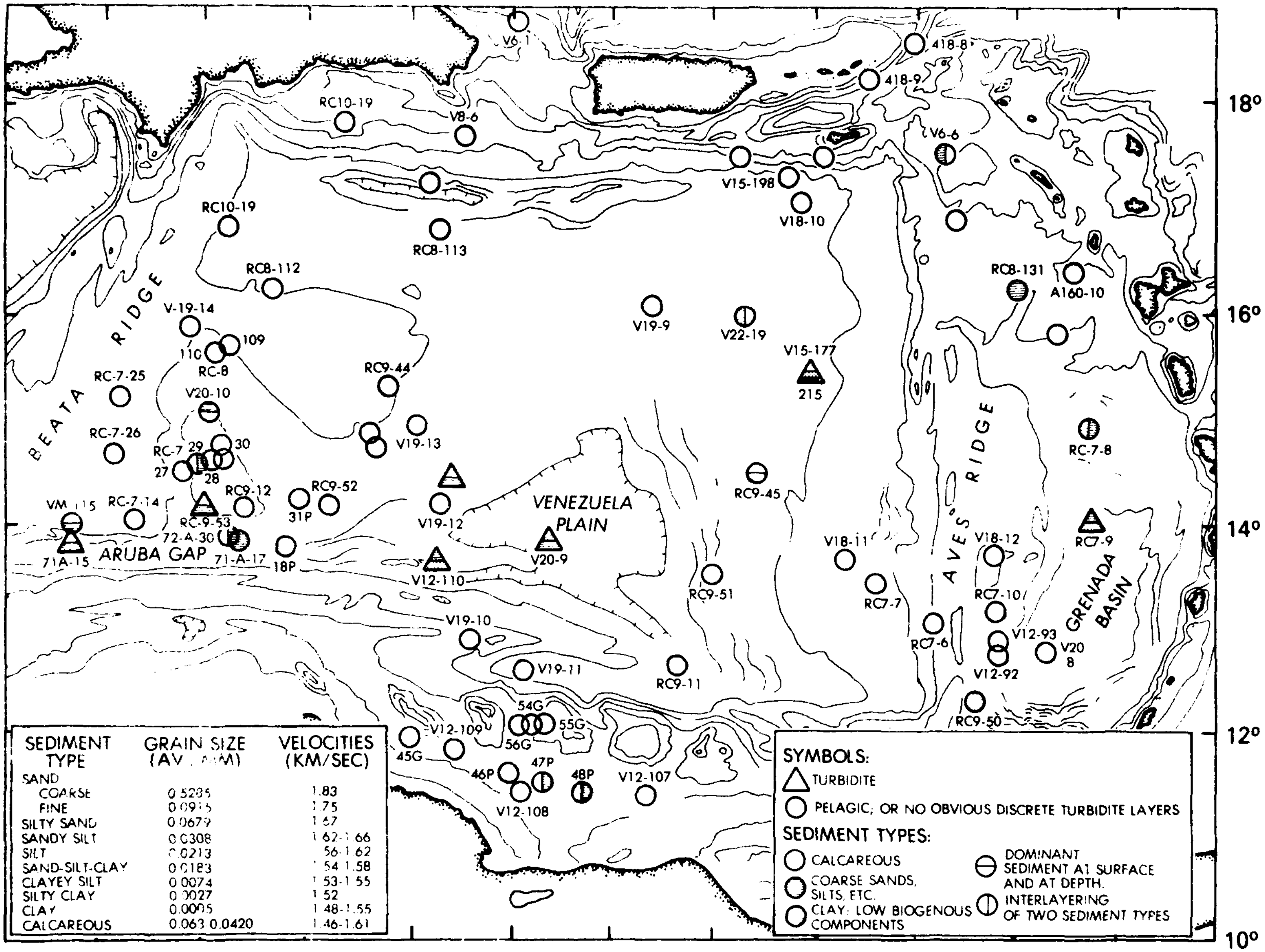

Figure 3. Map of surficial sediment types, with their grain size ranges and velocities. Core locations and descriptions (unpublished) were furnished by F. Bowles.

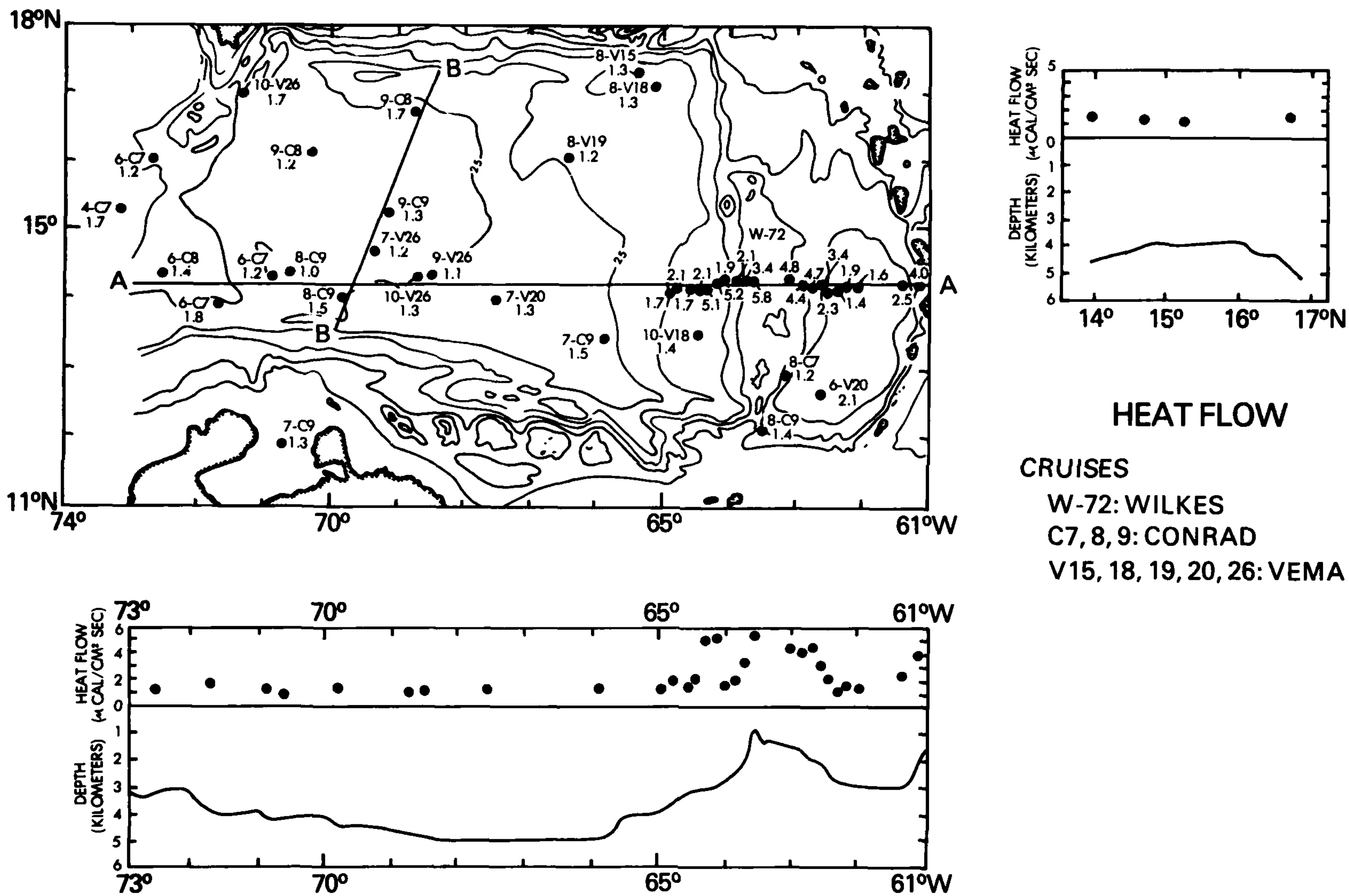

Figure 4. Heat flow map. At each station location the number to the right is the heat flow value. The number to the left designates the degree of reliability of the value on a scale of 1 to 10, and the cruise number. (Ex: 7-V26).

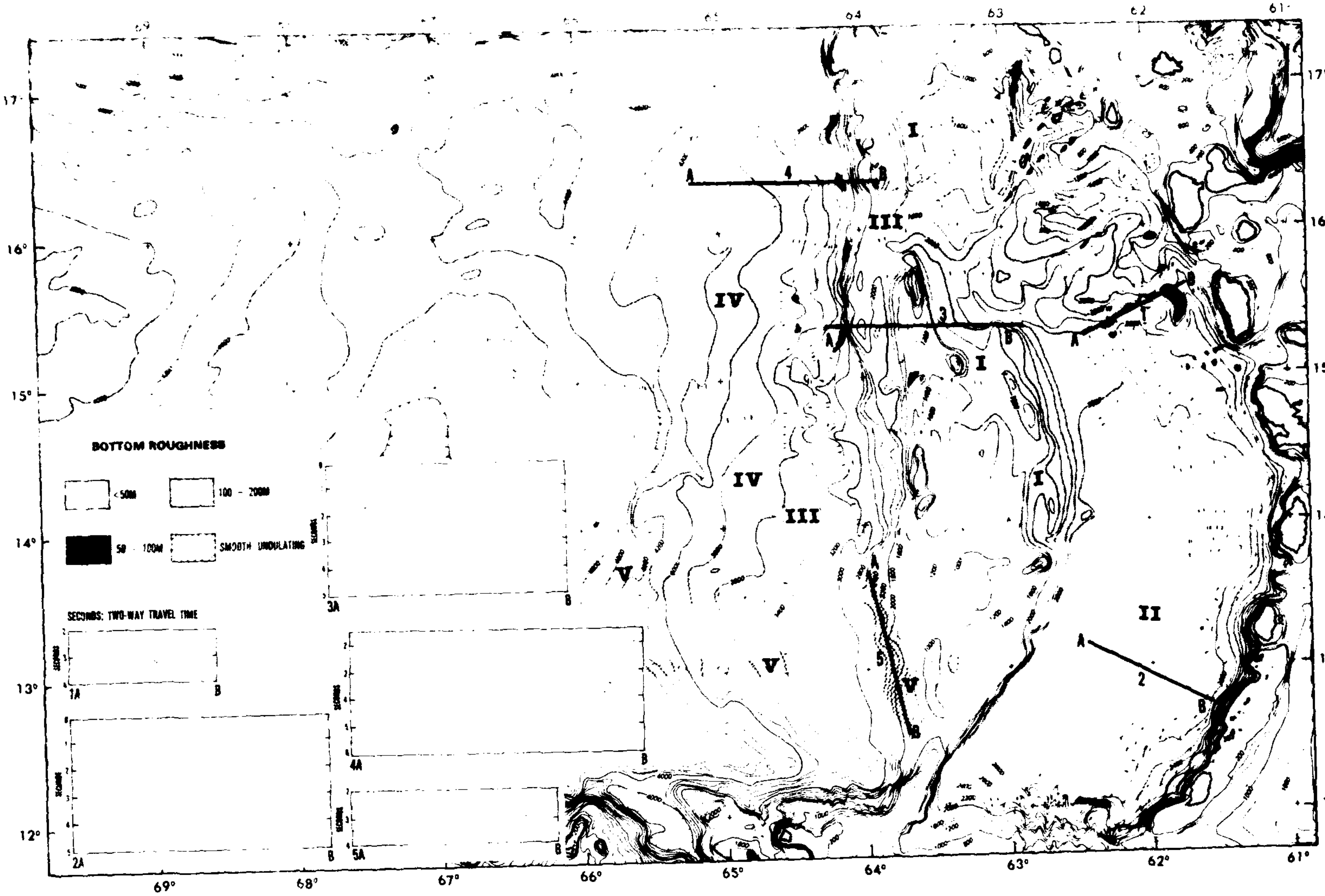

Figure 5. Bottom roughness map. Amplitudes of individual features are less than 200 m. Examples of topographic provinces are from seismic reflection records (WILKES, 1972). Provinces: 1. Microfeatures superimposed on larger topographic irregularities. 2. Grenada Basin; flat abyssal plain. 3. Rugged topography, exposed and buried peaks; Aves Ridge. 4. Slope to Venezuela Basin; west flank of Aves Ridge. 5. Large topographic undulations southwest of Aves Ridge.

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Sound speed map

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Geologic characteristics of the ocean floor can produce measurable effects on sound speed. Of significance are the intrinsic properties of sediments, their depth of burial, degree of consolidation, and temperature. Roughness of the sea floor can also affect sound transmission.

The series of maps in this report depict sound velocities beneath the eastern Caribbean as they vary both horizontally and vertically with geologic variation in the sea floor, together with the areal distribution of other important

geologic factors which affect sound speed. A brief discussion of each map is included in the text.

The sound speed map (Fig. 1) was compiled from all available seismic refraction data. Presented in columnar form, the map displays the variations in sound speeds which take place with depth beneath the sea floor; corresponding geologic variations are given. Also appearing on the map are contours of bottom water sound speeds.

North-south and east-west cross sections (Fig. 2) were constructed from the same data. These show the patterns of geologic and acoustic stratification in the region and the underlying basin structure.

Other important geologic factors which affect sound speed can be encountered at or near the surface of the sea floor; their distribution is shown on the remaining maps.

For the map of surficial sediments and their velocities (Fig. 3), sediment types were obtained from core descriptions. Grain size, a most significant factor that affects sound speeds in sediments, can be inferred from sediment types, and sound velocities are listed for each equivalent grain size category. On the heat flow map (Fig. 4), the values depicted were obtained from several sources. The degree of reliability of older data is noted at each station location.

The map of bottom roughness (Fig. 5) was constructed from seismic reflection records. Shown are areas of microtopography whose dimensions are too small to appear on most topographic maps, together with the topographic provinces.

The data were compiled from a variety of sources and aspects. More detailed information may be obtained form the references listed.